JPL Applications of Two-Phase Thermal Control Technology for Future Spacecraft

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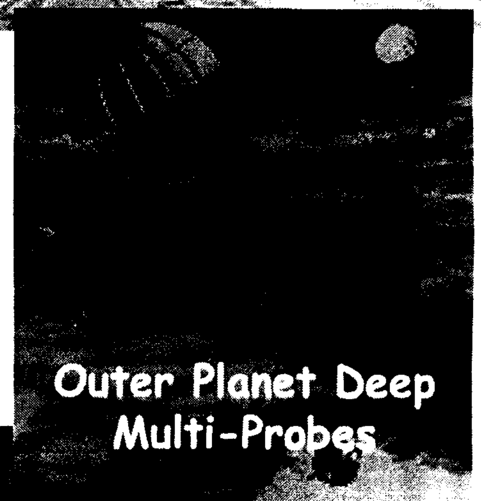
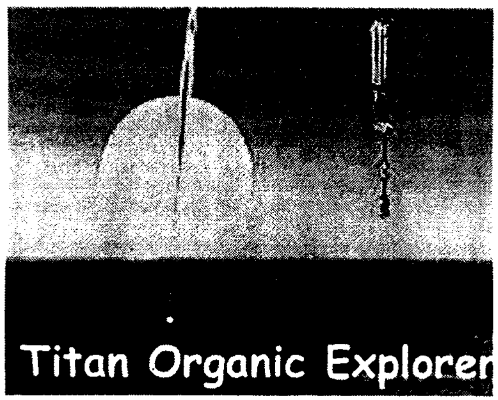
Future Space Science Missions at JPL

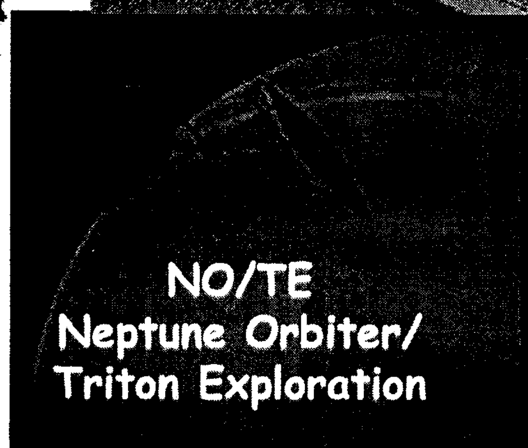
- **Mars missions**
  - Landers, rovers, in-situ production experiments, and robotic support for human colonization
  - MER (2003), Mars Orbiter (2005), Mars Mega Lander (2007), Mars μmission
- **Missions to comets/asteroids**
  - Comet Nucleus Sample Return Mission
  - Asteroid exploration and sample return
- **Missions to other planets**
  - Europa orbiter/lander (2005), Pluto/Kuiper Express (2008)
  - Saturn Ring Observer, Neptune Orbiter
- **Other missions**
  - Earth orbiting spacecraft/science payload
  - Space telescopes, instruments

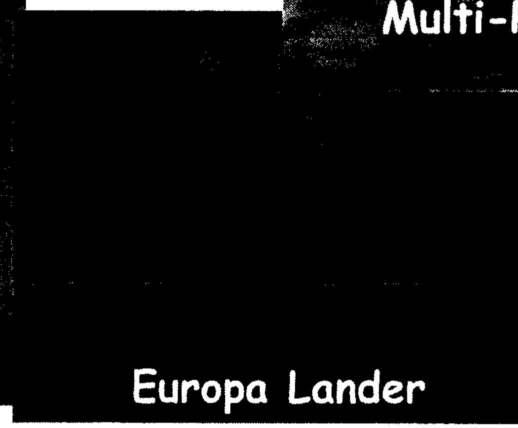
Future NASA Deep Space Missions

Advanced technologies needed in many diverse systems: Orbiters, landers, probes, rovers, penetrators, aerobots, aircraft, sub-surface, submarine, ...?





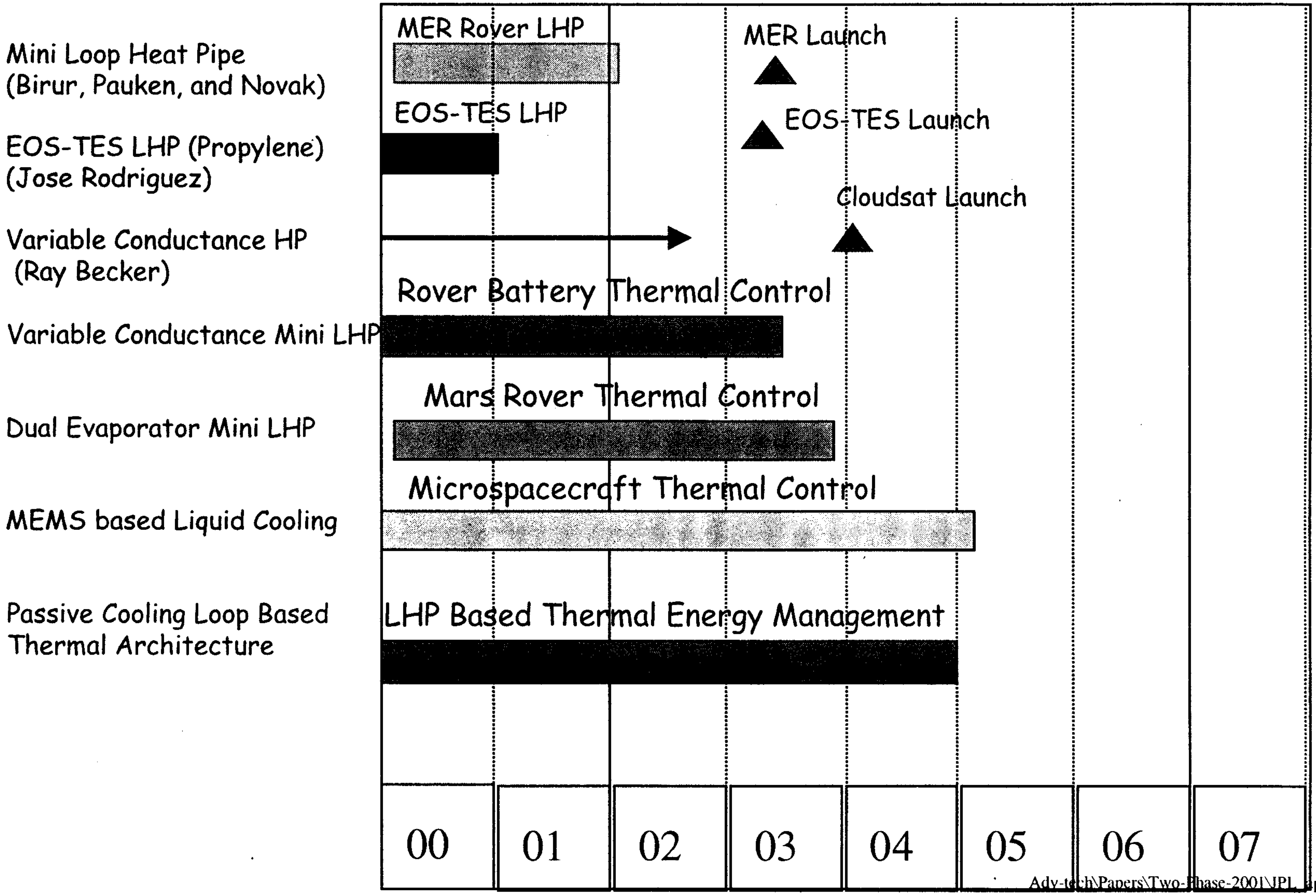




JPL Applications of Two-Phase Technology

- Fixed conductance heat pipes used on Wide-Field Planetary Camera (Hubble Telescope) in 1985
- Mars Pathfinder examined two-phase devices in 1993-94 but chose mechanically pumped liquid cooling loop
- EOS -TES has five LHPs (propylene) (2002 launch)
- Cloudsat is using seven VCHP (2003 launch)
- Mars Exploration Rover is using a mini LHP (2003 launch)
- Advanced technology mini LHPs investigated for Mars and deep space applications - variable conductance LHP and dual evaporator LHP
- MEMS based pumped liquid loop for micro/nano spacecraft

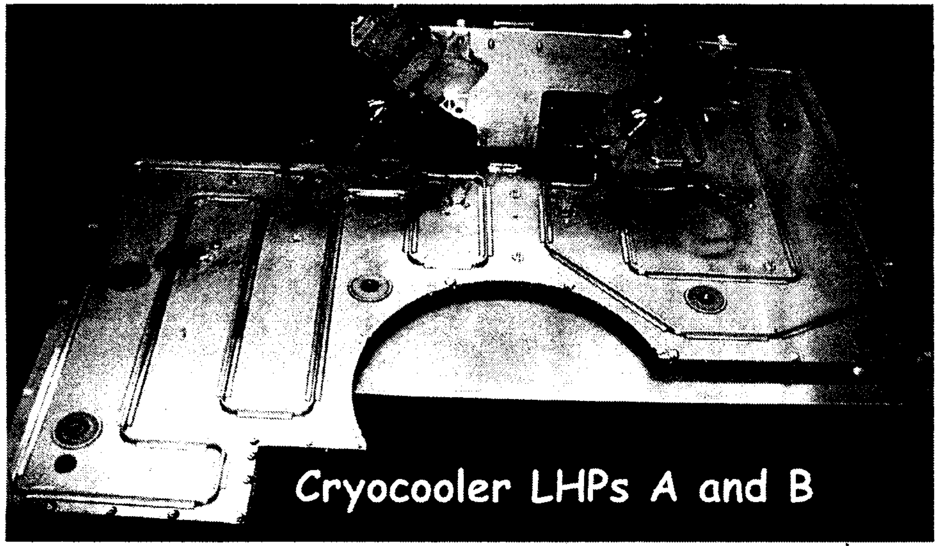
JPL Two-Phase Thermal Technology Roadmap

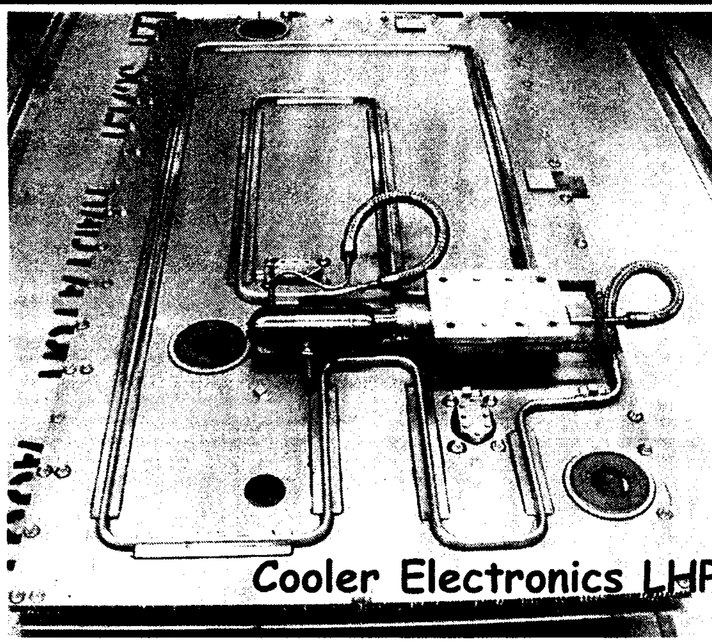


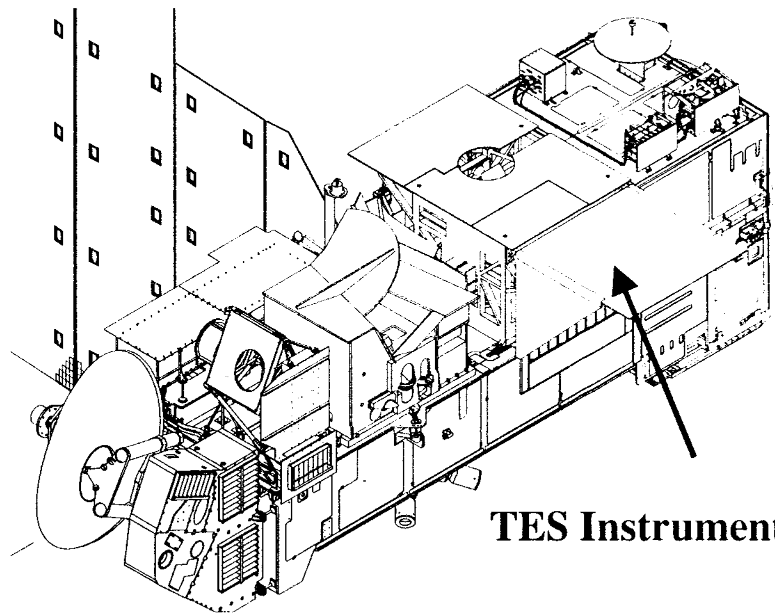
JPL Loop Heat Pipes on EOS TES Instrument

- Five LHPs are used on EOS-TES for thermal control (Jose Rodriguez, Thermal Lead)
- Heat transfer rate of 32 to 100 Watts
- Start up heater of 10 Watts and shut-off CC heater of 1.5 Watts used on all LHPs
- Propylene is used as working fluid to prevent freezing during periods when radiator temperature drops below -80 C
- LHPs used primarily as heat switch to prevent electronics temperature going below low limit

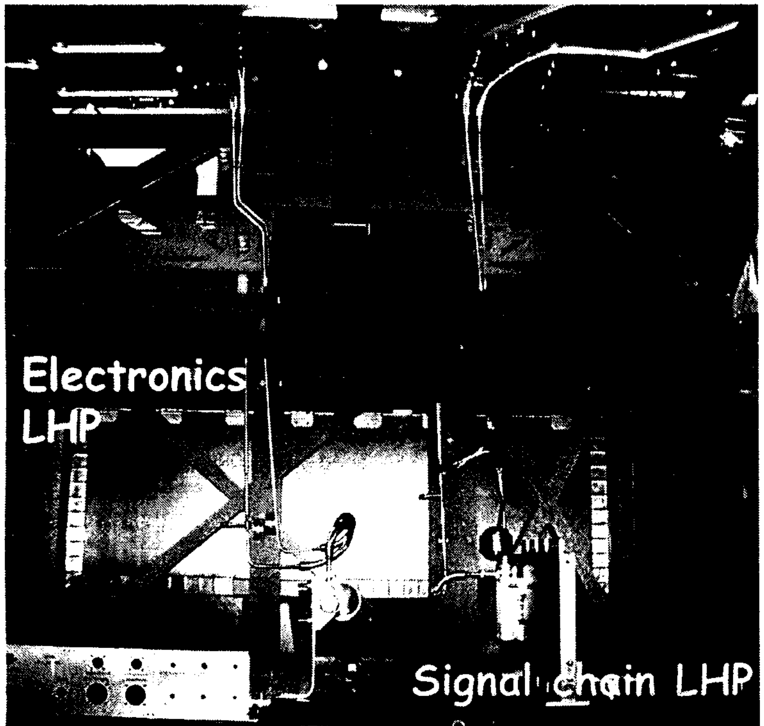
Loop Heat Pipes on EOS TES Instrument

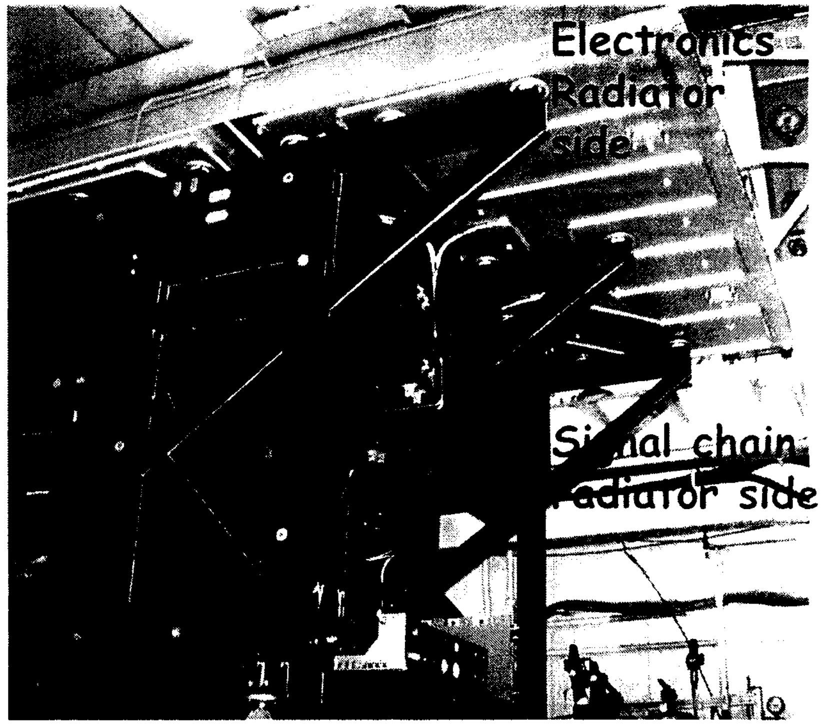






Loop Heat Pipes on EOS TES Instrument

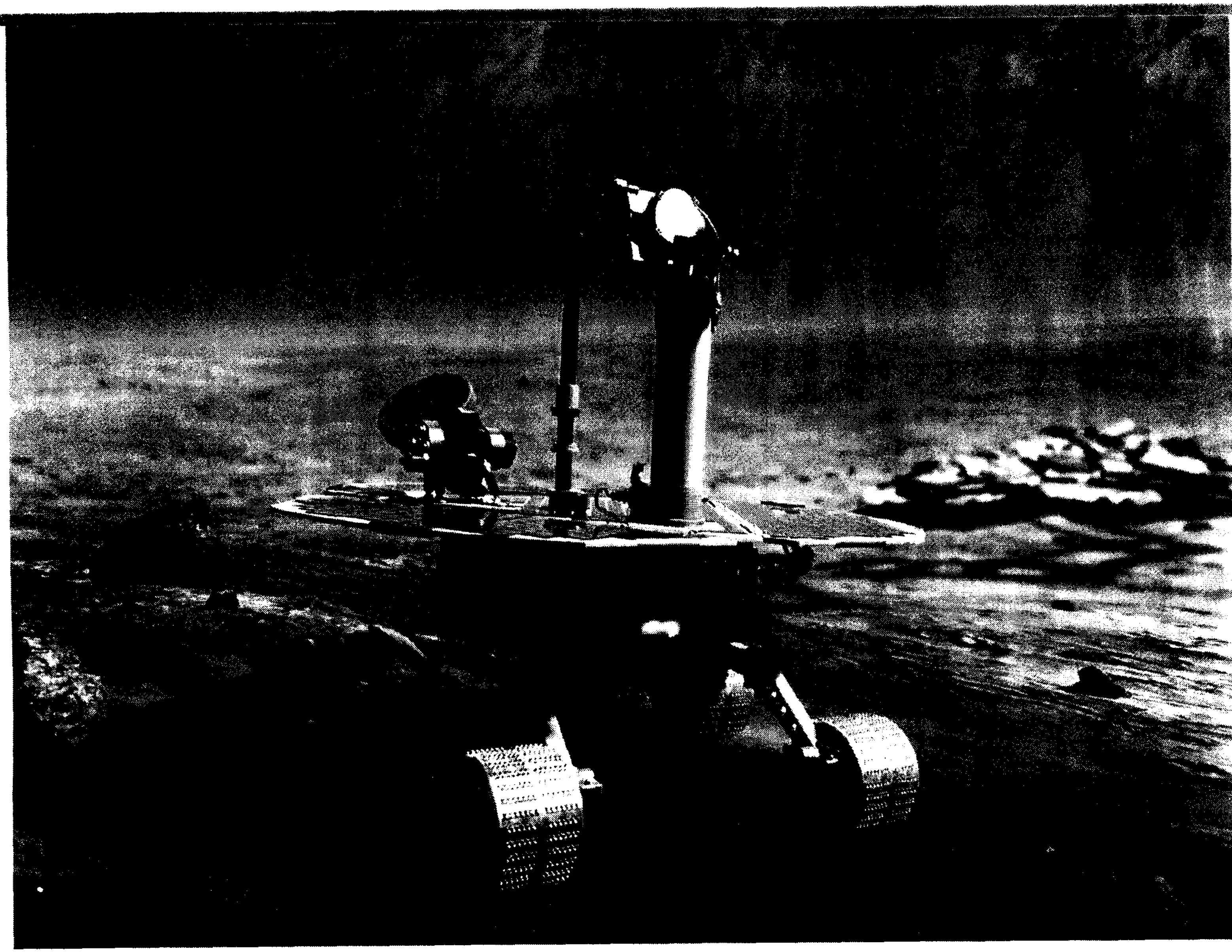




VCHP on Cloudsat Instrument

- Cloudsat uses seven VCHPs for thermal control (Ray Becker, Thermal Lead)
- Because of large surface area of heat source VCHPs were preferred over LHP
- VCHPs are about one meter long and have a heat transfer rate of 30 to 85 Watts
- Ammonia is used as the working fluid
- VCHPs used primarily as heat switch to prevent electronics temperature going below low limit

Mars Exploration Rover Conceptual View



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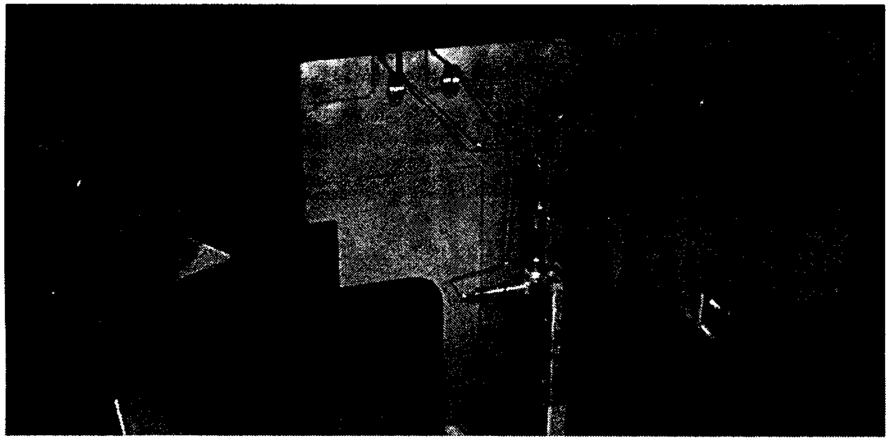
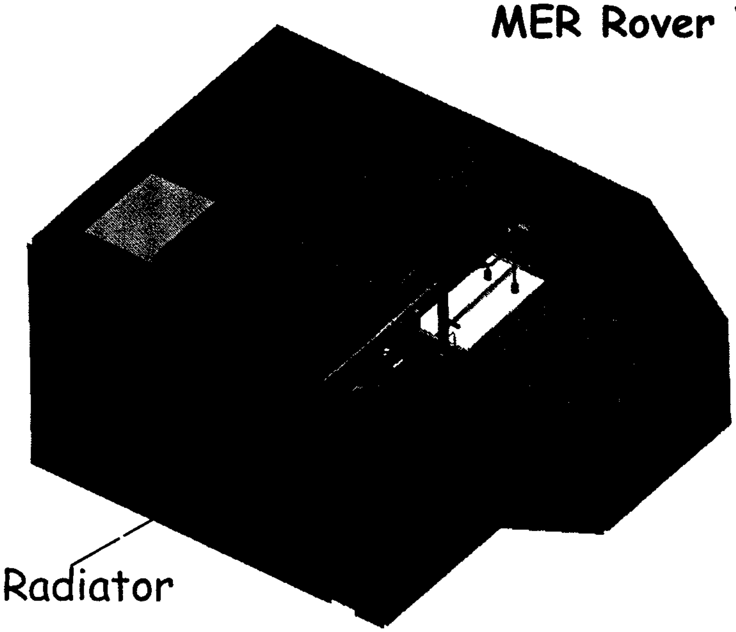
MER Rover Miniature Loop Heat Pipe





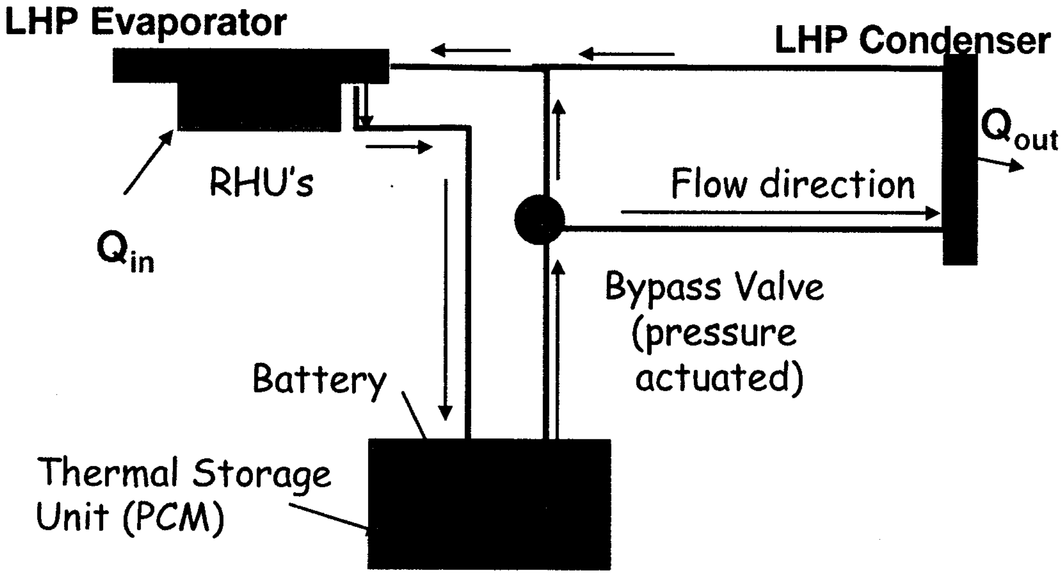
Description

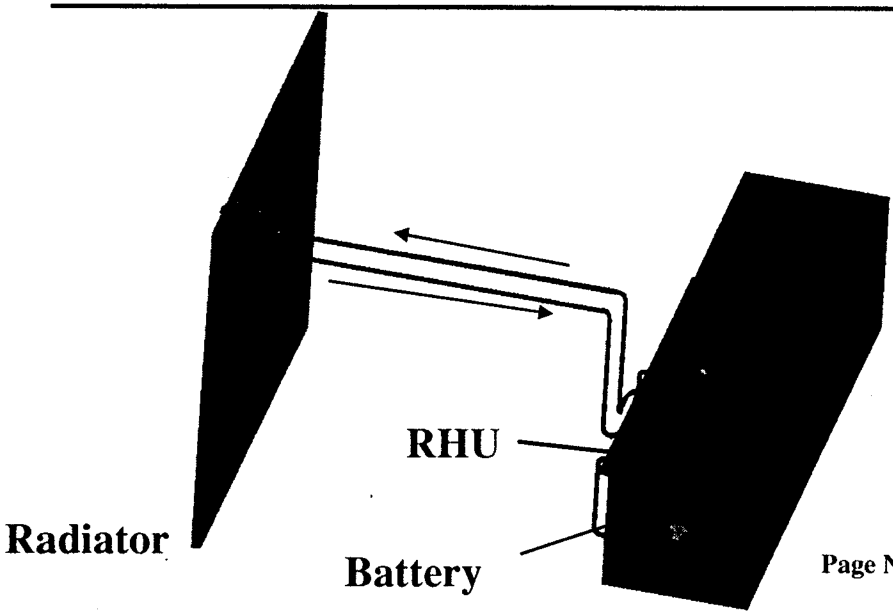
- Mini loop heat pipe with 0.5 inch nickel wick and ammonia as working fluid
- Light weight (less than 150 gms (with out the radiator to transfer 50 W)
- Vapor and liquid lines are 1/16 inch dia provides enormous flexibility in locating heat sources and sinks on the spacecraft

Application

- This LHP removes heat from the MER rover SSPA during the day on Mars, start up heater and CC heater used for control
- Light weight and flexibility allows for easy mechanical integration in the rover
- Small dia tubing allows the condenser to freeze and thaw during Martian diurnal cycles

Variable Conductance Loop Heat Pipe

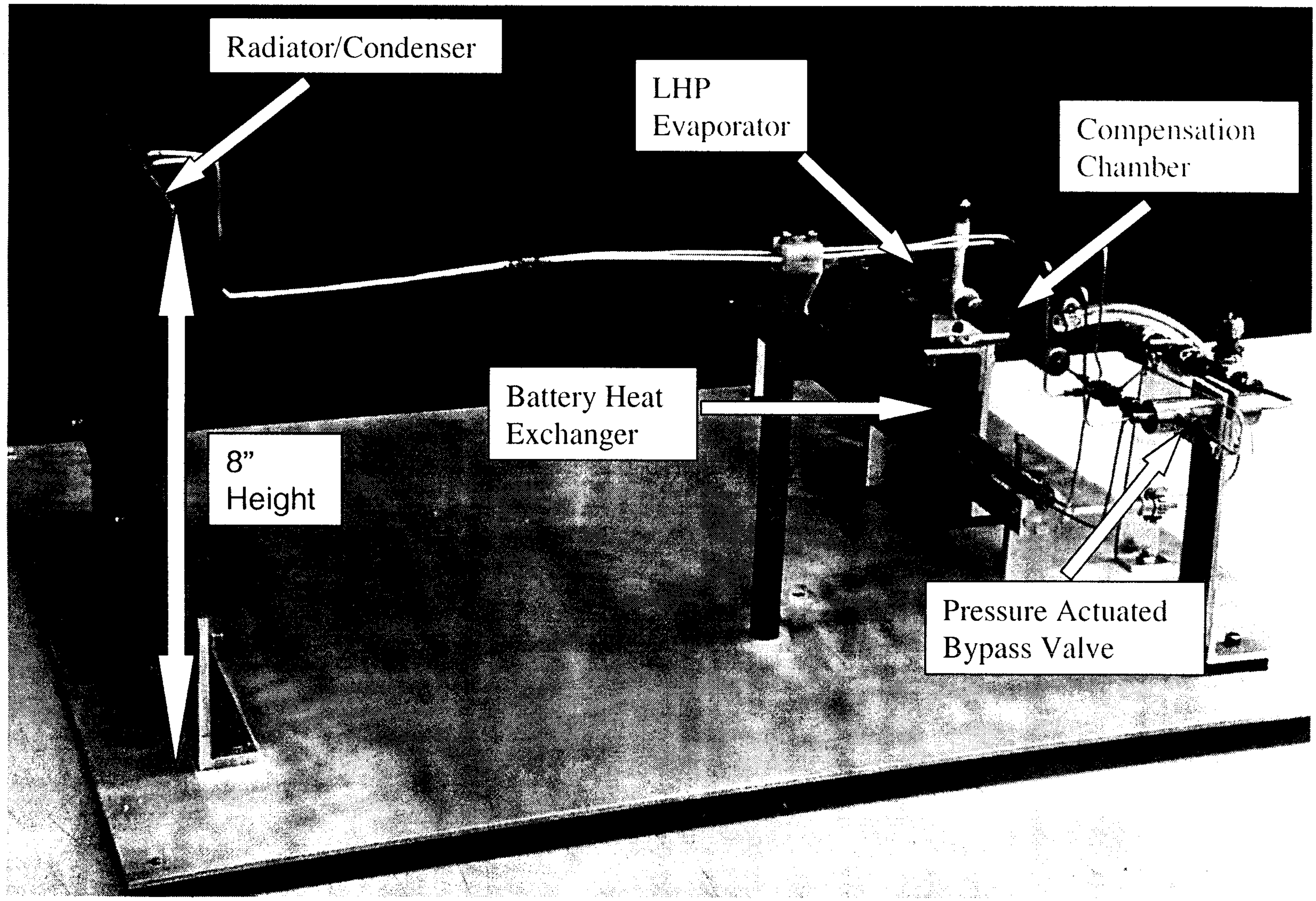




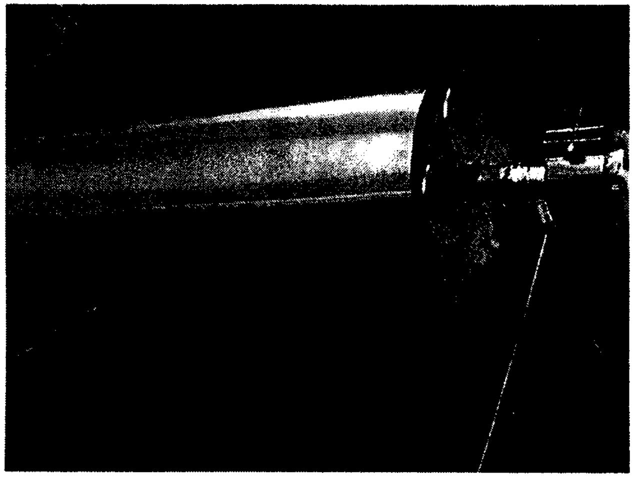
Application

- VCLHP evaluated for Mars battery thermal control
- Backpressure actuated valve is used to bypass the radiator
- Small dia (1/16") tubing allows the condenser to freeze and thaw during Martian diurnal cycles
- Performance and condenser freeze/thaw tests (100 cycles) conducted during late 2000

Variable Conductance Loop Heat Pipe



Phase Change Thermal Storage Technology



Description:

- Phase change material (PCM) utilizes latent heat to protect batteries against low temp. extremes by providing thermal storage
- PCM stores excess heat when available and releases the heat when needed
- The technology is simple, reliable, and mass efficient

Current Status:

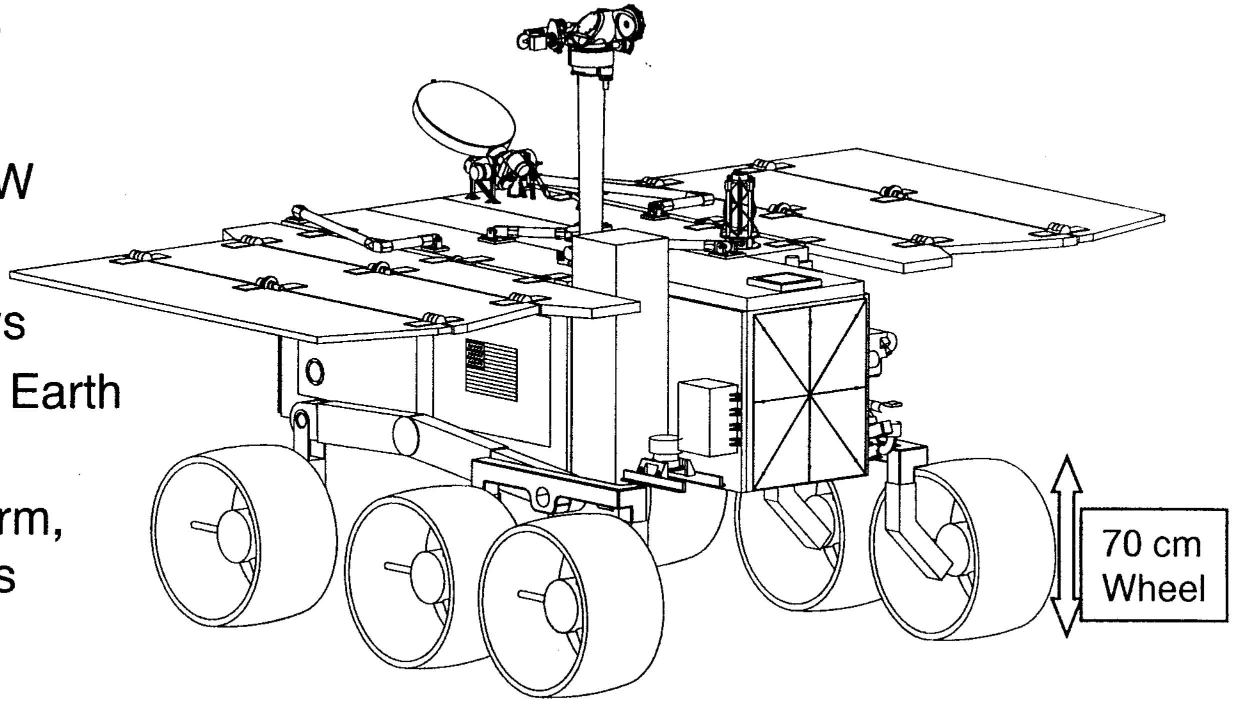
- Dodecane PCM material (-10 C MP) encapsulated in a carbon fiber matrix
- A battery/PCM capsule was fabricated by ESLI for JPL
- It is integrated with miniature LHP and being tested at JPL in a simulated Martian environment to evaluate rover battery/electronics thermal control

Future Development:

- Investigate PCM materials with lower MP for lower temperature operations (below -20 C)
- Develop and qualify low mass system for thermal energy management on Mars landers, in-situ experiments and Microspacecraft missions

Thermal Control for Future Mars Rovers

- Mass = 200- 750 kg
- Solar Array Area = 7.0 m^2
- Wheel diameter = 70 cm
- Max Power = 100 to 175 W
- Secondary Battery
- Design Life = 90 -180 days
- Telecom links to orbiter & Earth
- Payload: cameras, spectrometers, instrum. arm, drill, sample cache & Mars Ascent Vehicle
- Thermal Control:
  - CO2 gas gap insulation
  - up to 30 RHU's
  - Radiators & LHPs or Pumped Fluid Loop



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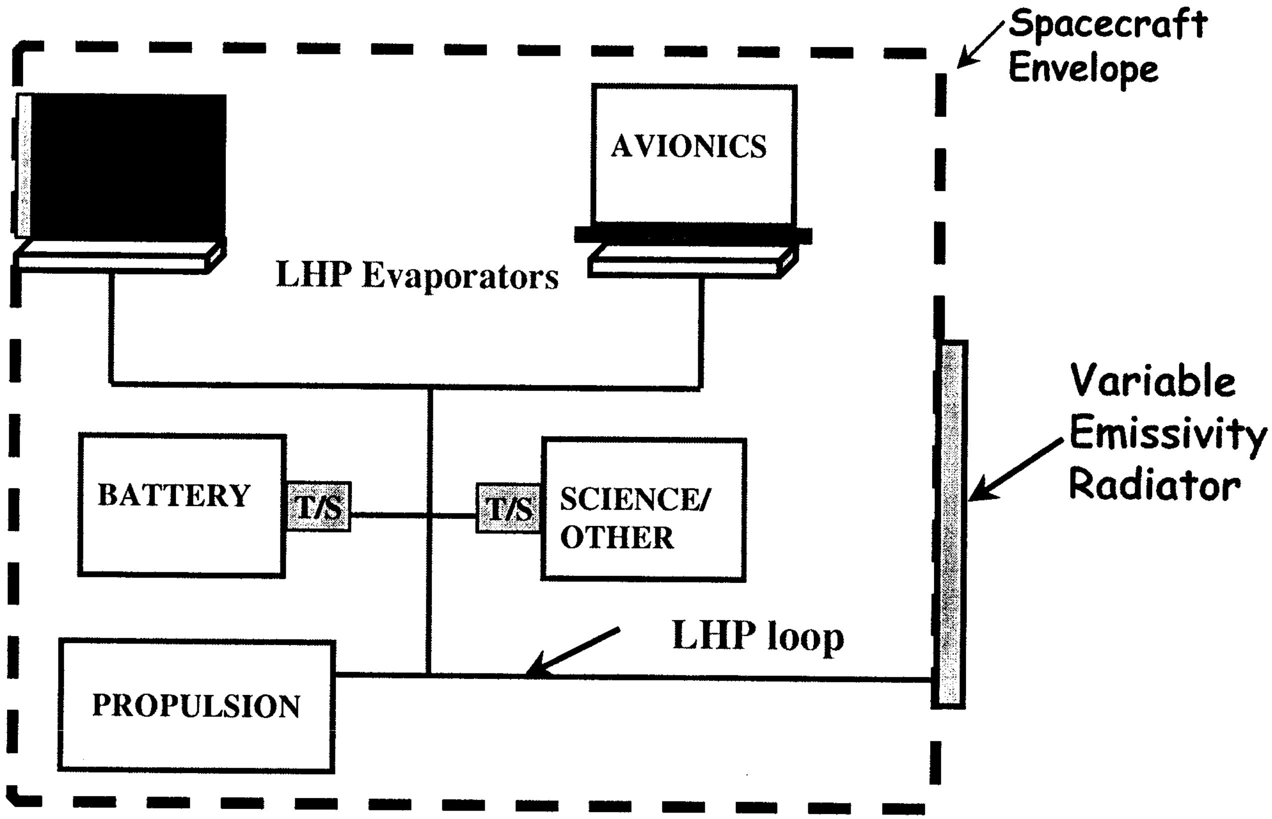
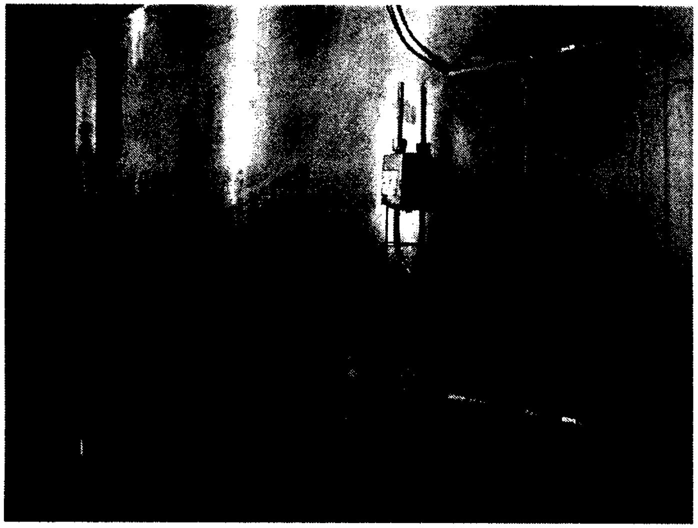
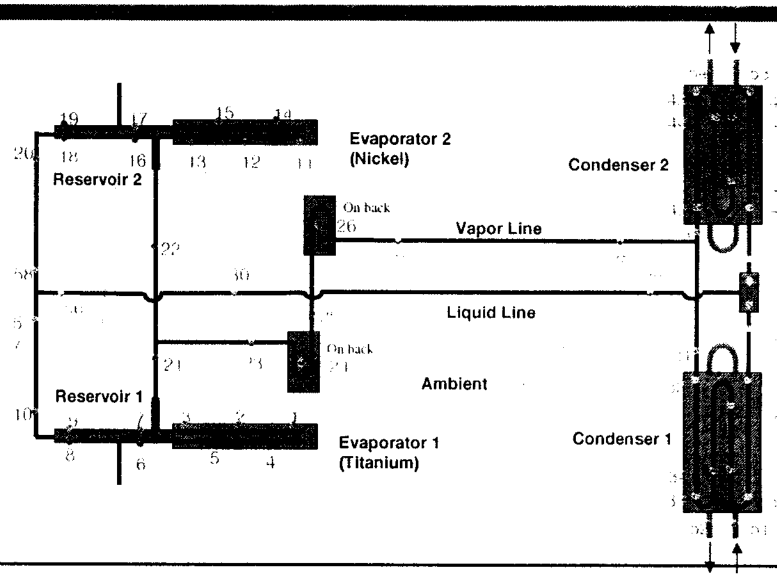
Advanced Thermal Architecture

Based on Passive Cooling Loop



Dual Miniature Evaporator Mini LHP





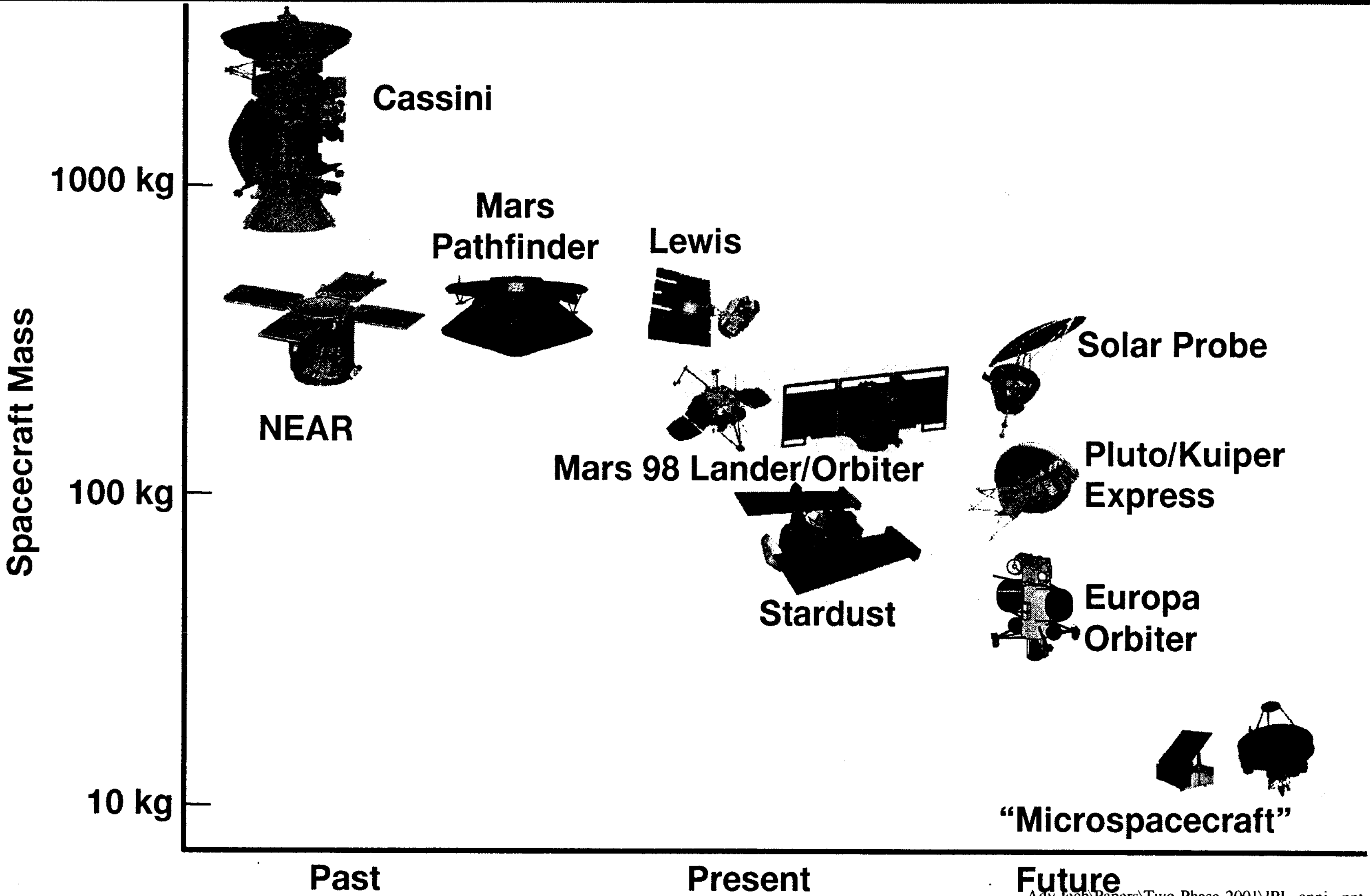
Participants & Facilities

- JPL is investigating this technology for space applications (Mars rover & microspacecraft)
- Tests performed at GSFC during FY00 and more tests at JPL in 2001 for its applications for passive thermal control architecture
- Dynatherm Corporation fabricated the dual evaporator (Ni and Ti wicks) miniature loop heat pipe

Mission Impact & Future Applications

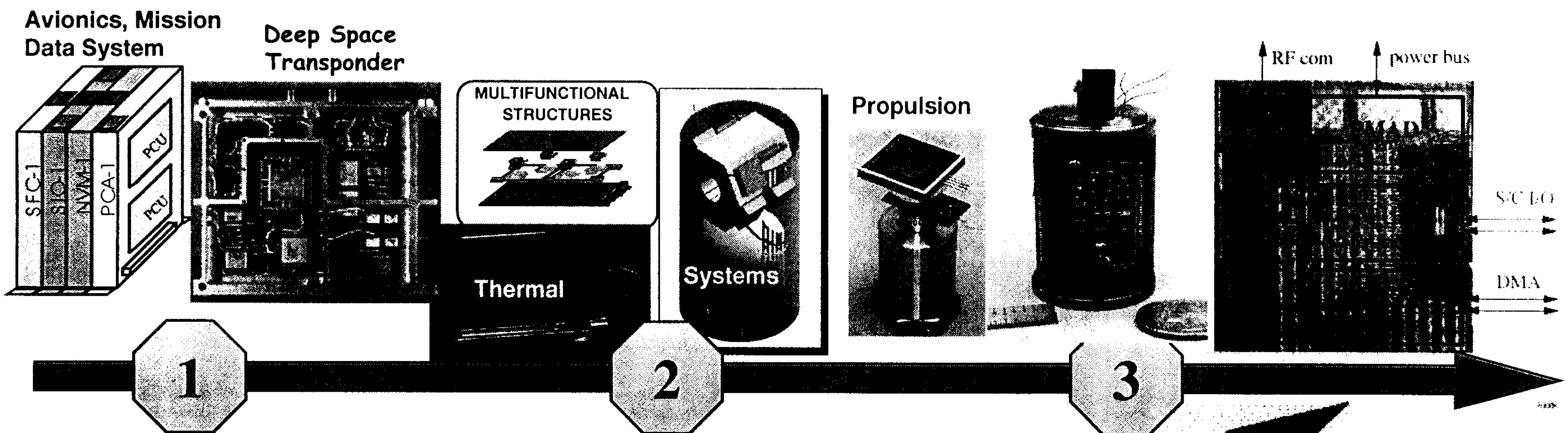
- This technology reduces S/C thermal control mass and provides enormous flexibility
- This is a key technology for enabling Integrated Thermal Energy Management System
- This technology is applicable to small & large S/C and planetary vehicles thermal control

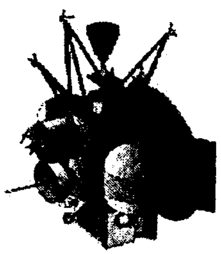
Trends in Spacecraft Size of Deep Space Missions



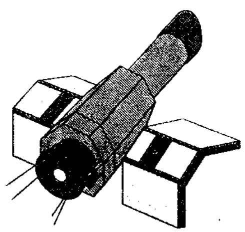
Overview of Future Space Missions

2000 | 2004 | 2008 System on a Chip

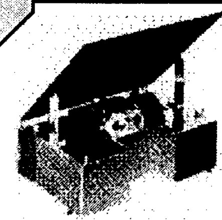




03-05 User Launches:
- Europa Orbiter
- Solar Probe
- Discovery

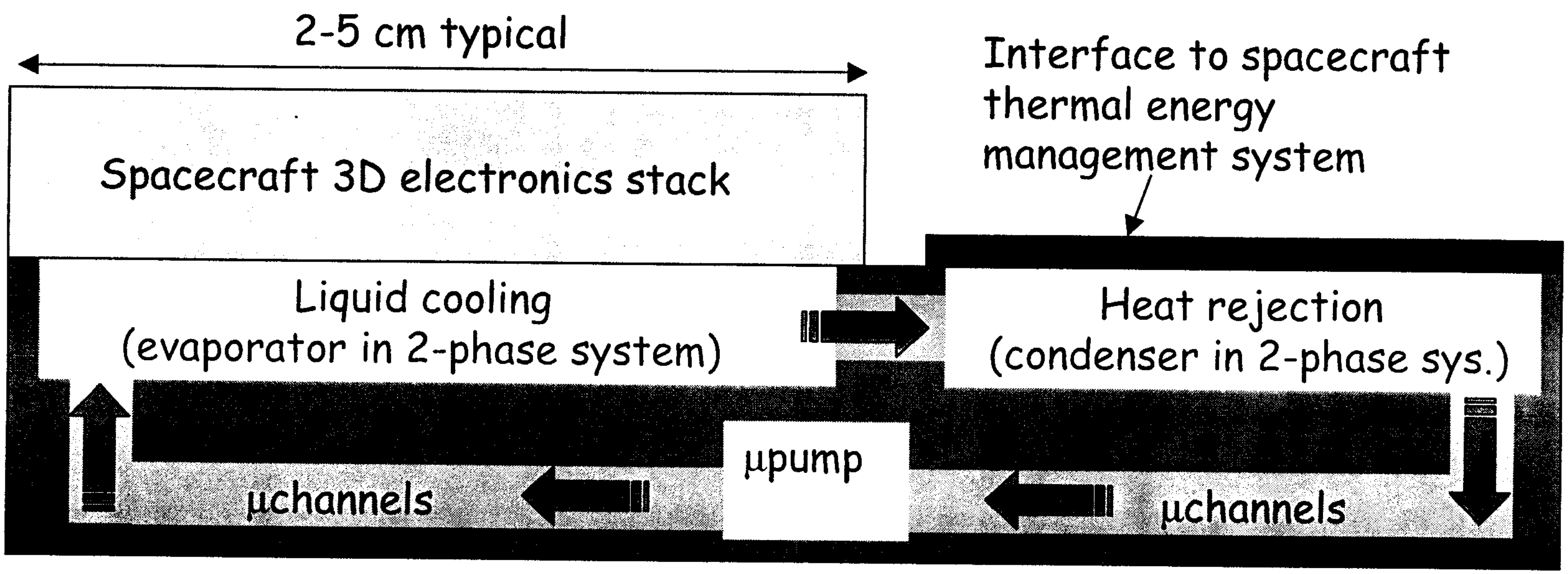


05-09 User Launches:
- CNSR
- Europa Lander
- Titan Organic Explorer
- Venus Sample Return
- Neptune Orbiter
- Saturn Ring Observer



09-12 User Launches:
- Micro and Nano-spacecraft
- Terrestrial Planet Finder

MEMS Pumped Liquid Cooling System Concept



MEMS-based technologies needed:

- Microchannels
- Micropumps
- Microvalves
- Interconnects

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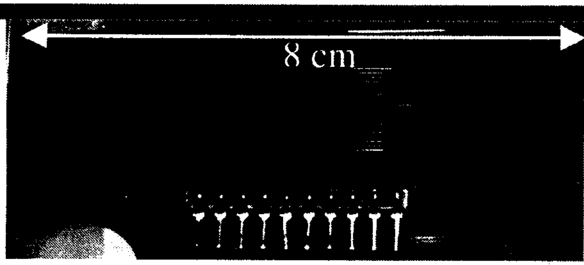
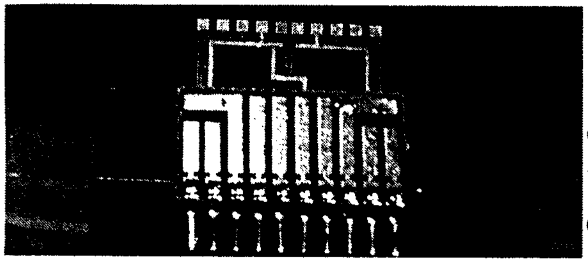
Micro/Nano Spacecraft-Microcooling Tests



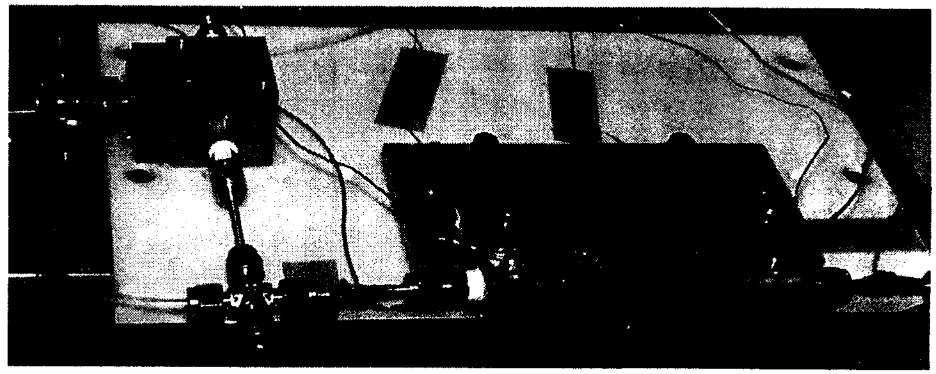
Silicon wafer showing the μ-channel side



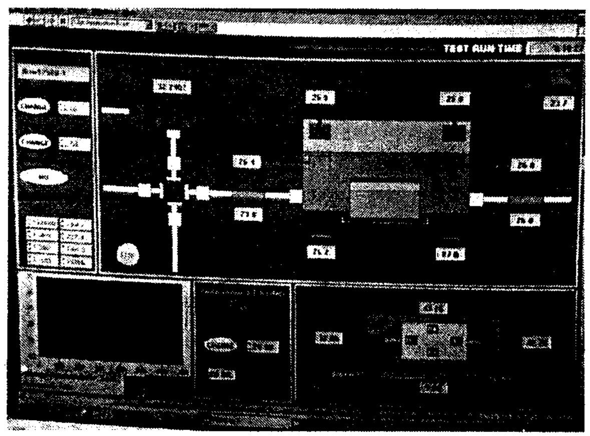
Wafer backside showing the embedded heater thermistors & connector

Microchannels on a silicon wafer with a connector for heaters and temperature sensors (JPL Micro Device Lab)

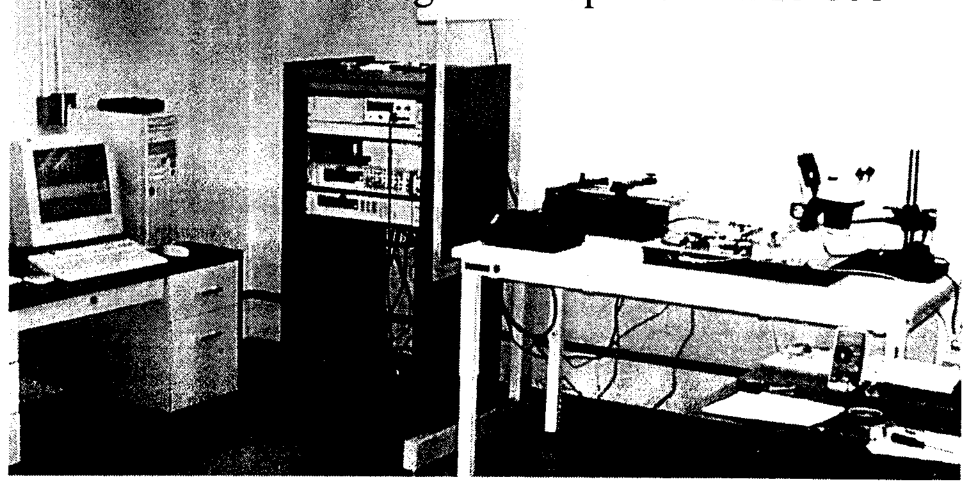
Microchannel in the test setup



LabView Data acquisition Software



Microcooling test setup in JPL B18-101



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Conclusions

- Two-phase technology is an important thermal control element of JPL's future space science missions
- Two-phase technologies are being investigated as both enabling and enhancing technologies
- These technologies span both near/far term missions and large/micro spacecraft
- JPL is conducting technology development in collaboration with other organizations